III.4 Energy Systems Analysis: Hydrogen Deployment System Modeling

Walter Short (Primary Contact), Keith Parks
National Renewable Energy Laboratory (NREL)
1617 Cole Blvd.
Golden, CO 80401
Phone: (303) 384-7368; Fax: (303) 384-7449; E-mail: walter_short@nrel.gov

DOE Technology Development Manager: Fred Joseck
Phone: (202) 586-7932; Fax: (202) 586-9811; E-mail: Fred.Joseck@ee.doe.gov

Start Date: January, 2004
Projected End Date: September, 2007

Objectives

- Quantify the potential of wind energy and other distributed sources to produce hydrogen in the United States by 2050.
- Incorporate central hydrogen production technologies into the hydrogen deployment system (HyDS) model and assess the relative contributions of distributed and central production technologies.
- Assist DOE with determining research directions for hydrogen technology projects.

Technical Barriers

This project addresses the following technical barriers from the Systems Analysis section (4.5) of the Hydrogen, Fuel Cells & Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- A. Lack of Prioritized List of Analyses for Appropriate and Timely Recommendations
- E. Lack of Understanding of the Transition from a Hydrocarbon-Based Economy to a Hydrogen-Based Economy

Approach

- Develop HyDS, a multi-regional, multi-time-period model of hydrogen production in the United States including the impacts of electrolysis on capacity expansion in the electric sector.
- Estimate market potential of hydrogen from wind and other sources in the United States for the next 20–50 years under different technology development and policy scenarios.

Accomplishments

- Added electrolysis/storage/fuel cells to HyDS in the general grid as a storage option.
  - Conclusion: The use of electrolyzers and fuel cells at wind sites to store/shift wind generation from off-peak to on-peak periods occurs only at remote, well-developed wind sites with good wind resources.
- Modified HyDS to incorporate cost synergisms with wind; i.e., in-tower storage and reduced cost of joint control system for wind and electrolyzers.
  - Conclusion: Where wind resources are close to transportation fuel demand centers, electrolyzers at wind farms may be preferred to electrolyzers distributed close to the demand center.

   - Conclusion: Wind's most substantial contribution may be as power to the grid to meet the additional demand for power required by distributed electrolyzers (~20 gigawatt electric [GWe]).
- Developed initial regional supply curves for large-scale production of hydrogen from central sources other than wind that include economies of scale for both production and inter-city pipelines.

Future Directions

- Add other hydrogen sources, such as biomass, coal gasification, and nuclear high-temperature production of hydrogen.
- Incorporate economies of scale in production for these new sources.
- Incorporate pipeline economies of scale, discrete pipeline sizes, and increasing capacity utilization after installation.
- Replace the gas price trajectory currently taken from *Annual Energy Outlook 2005*, with a simple gas pricing module that is responsive to the increase in gas demand imposed by hydrogen production by steam methane reforming (SMR).

Introduction

DOE has set an objective to identify and evaluate transition scenarios consistent with developing infrastructure and hydrogen resources. This project specifically contributes to this goal by quantifying the potential of various production technologies to produce hydrogen in the United States by 2050. It also quantifies the potential for distributed versus on-site production of hydrogen from electricity-based technologies (e.g., electrolyzers). More generally, it models the impact of hydrogen on the electricity sector, thereby quantifying the need for additional infrastructure in this sector. New efforts begun in May 2005 will add central hydrogen production options to the model.

Approach

The analysis utilizes a model called HyDS, which is a multiregional, multi-time-period model of hydrogen production in the United States. HyDS models hydrogen production from electrolysis distributed at the load center or at wind farms. These electricity-based technologies compete against distributed SMRs located at the demand centers. Efforts under way at this time (June 2005) will expand the model to include central hydrogen production from gas, coal and other sources.

Since our last annual progress report, we improved HyDS to better model synergies between the electricity sector and hydrogen production.

- Improved HyDS to use hydrogen production as a storage medium for the electric grid as a whole, not just to back-up wind generation.
- Modified HyDS to incorporate hydrogen production cost synergisms with wind; i.e., in-tower storage and reduced cost of joint control system for wind and electrolyzers.
- Developed initial regional supply curves for large-scale production of hydrogen from central sources other than wind that include economies of scale for both production and inter-city pipelines.

Results

Figures 1 and 2 show distributed hydrogen capacity and production, respectively, by technology through 2050 estimated based on the HFCIT program cost and performance goals. Figure 1 shows that

- Distributed electrolyzers have the potential to be the largest electricity-based hydrogen generation technology with 20 GWe of capacity by 2050.

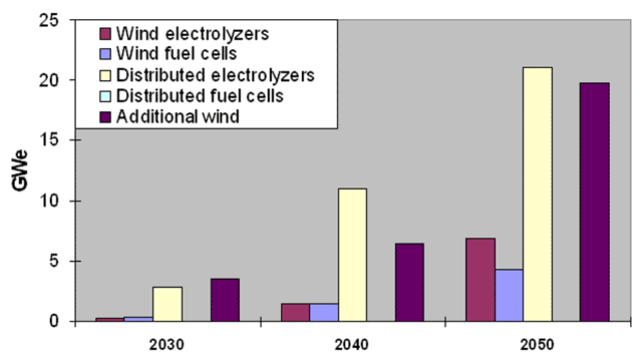

Figure 1. Hydrogen Capacity by Technology Type

- At the program's goal for costs, distributed hydrogen production, storage, and electricity generation via fuel cells has little market potential to meet electricity peak demands in the general electric grid.
- Electrolyzers and fuel cells sited at wind farms may have some potential by 2050 because they provide storage and allow dedicated transmission lines for the wind farms to be downsized.
- Wind's greatest contribution may be to supply electricity for distributed electrolyzers.

Figure 2 shows that:

- Electrolyzers sited at the wind farms are operated around the clock using grid-supplied power to fill in when the wind is not blowing.
- Although wind-sited fuel cell capacity in Figure 1 is almost as large as wind-sited electrolyzer capacity, very little of the hydrogen produced by the electrolyzers is used in the fuel cells (most goes for use as a transportation fuel). This is because the fuel cells operate only during peak electric periods when the wind is not blowing (so they require very little hydrogen), while the electrolyzers are operating around the clock (producing relatively more hydrogen).
- Figure 2 does not include hydrogen produced from natural gas by distributed steam methane reformers (SMRs). With the relatively low gas prices taken in this analysis from the *2005 Annual Energy Outlook* (EIA), hydrogen from SMRs swamps that from electrolysis. This may change in our end-of-this-year results as we will be modifying our gas price assumptions to account for gas price increases that would accompany significant use of gas in SMRs.

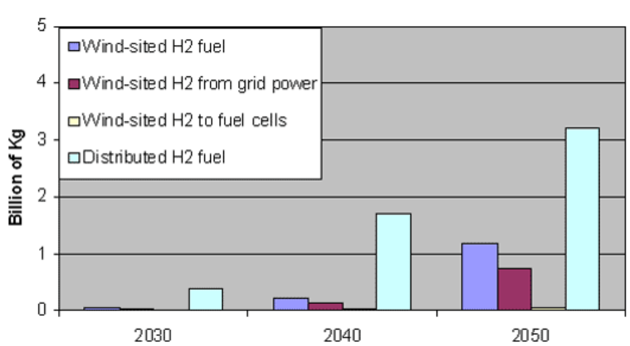

Figure 2. Hydrogen Produced by Technology Type

Not shown in the graphs is the geographic location of the wind-sited hydrogen capacity. These technologies are predominately located in two very different types of sites:

- At wind sites close to the hydrogen demand centers (eg cities). These sites can take advantage of the cost synergisms of combined controls and hydrogen storage in the wind towers without paying much to transport the hydrogen to the cities' distribution systems.
- At wind sites that are remote, already partially developed, but have good remaining potential. These sites have three advantages for the use of hydrogen for electricity storage, i.e. for an electrolysis/fuel cell system. They have the hydrogen-wind cost synergisms mentioned above for the close-in sites. They can reduce the size and therefore the cost of the long transmission system required at a remote site by using the storage to move the peak wind generation to the valleys. And electricity storage is more valuable because without it the output of any new wind turbines installed would be highly correlated with that of the existing turbines at the site yielding no capacity value for the new wind.

Conclusions

- The most economic electric source of hydrogen for transportation fuel is electrolyzers distributed at the city gates where hydrogen transportation costs are minimized.
- The most economic overall source of hydrogen today is natural gas steam methane reforming. Additional analysis is required to ascertain whether this will remain true when gas prices rise in response to hydrogen-production-driven increases in demand for natural gas.
- Wind resources may be best used to meet additional demand for power required by distributed electrolyzers.
- In cases where wind resources are close to the hydrogen demand centers (e.g., cities), electrolyzers at the wind farms may be preferred over distributed electrolyzers closer to the demand centers.
- The use of electrolyzers or fuel cells as a storage device for electricity is potentially limited to remote, well-developed wind sites with good wind resources.